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Satellite Sensed Skin Sea Surface Temperature; Its relationship to Surface Heat Exchange Processes and Mapping SST in TOGA COARE

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Introduction

During the past year, substantial progress has been made under our grant to study skin sea surface temperature (SST). Our work falls into two primary areas. The first involves the analysis of skin SST measurements collected in previous years aboard the R/Vs Malcolm Baldrige and John V. Vickers. This analysis includes the study of the bulk-skin temperature difference and its relationship to the air-sea heat flux. The second area involves the mapping of SST in the TOGA COARE domain. This report will detail the progress that has been made and the planned research for the following year.

In Situ Observations of Skin SST

Our study of skin SST has focused on three different data sets, two of which were collected under this grant. The first data set and the only one not collected under this grant was taken aboard the German F/S Meteor in 1984. Analysis of this data set was presented by Schluessel et al. (1990). We have used this data set to test some new ideas and as a source of comparison for the data we have collected. The second data set was collected in 1990 in the central and southern Pacific Ocean aboard the NOAA Ship Malcolm Baldrige. The final data set was collected in March of 1993 aboard the R/V John V. Vickers during CEPEX in the equatorial Pacific.

During the past year, we were finally able to process the Malcolm Baldrige data to the point that we will be able to do some useful analyses. The original problem with the data was that the electronics used in measuring the temperature in our reference bucket were subject to severe drift when heated by the sun. Without accurate reference temperatures for calibrating our radiometer, we could not obtain any valid skin temperature measurements. Through careful analysis of the instrumentation after return and use of air temperature data during the second leg of the cruise, we have applied a correction for the drift caused by heating and created a skin SST time series for the second leg. During the first leg we did not have the extra measurements from our system necessary for this correction.

The skin SST record appears to be good despite the difficulties in generating it. The skin SST values show excellent correlation with the bulk values and only a small offset. A sample of the bulk and skin SST time series for one day of the cruise is shown in Figure 1. The solid line represents the skin temperatures and the dotted line represents the bulk temperatures. These observations are consistent with our current understanding of the bulk-skin temperature difference (ΔT). With reasonable skin SST values, we are now

ready to begin our analysis of the data. This task should be completed in the following year.

In March of last year, we collected another skin temperature data set. This data was collected aboard the R/V John V. Vickers in the tropical Pacific as part of CEPEX. The processing of this data has proceeded much more rapidly and is already nearly complete. In this experiment, the skin temperature data was collected with the new Ophir multi-band infrared sea-truth radiometric calibrator (MISTRC). This radiometer possesses two detectors and multiple filters which provide measurements of the ocean surface at 3.7, 4.0, 10.8, and 11.8 μm. In addition to the unpolarized measurements at 3.7 and 4.0 μm, we also have measurements at these frequencies with wire grid polarizers which blocked incident light with horizontal polarization.

Using a well-mixed reference bucket of sea water at a known temperature, we have calibrated the skin temperature measurements in each spectral band using the procedure described by Schluessel et al. (1990). Time series for each channel have been created and compared with each other and a time series of the bulk temperature to check the quality of the data. The data generally looks good, although the multiple channel measurements have allowed us to detect some potential problems with the bucket calibration system that could not be detected with a single channel radiometer. The mid-range infrared measurements have very low noise levels and the polarized measurements of the reference bucket match very well with the measured temperature. The polarizers appear to have succeeded in suppressing most of the effects of reflected sunlight which pose a major problem at these shorter wavelengths. There is still a slight warming (~ 0.1°C) of the polarized measurements relative to the bucket during the day, but the problem is much less severe than with the unpolarized channels. The 10.8 and 11.8 μm measurements do not suffer from problems with reflected solar radiation but they are subject to a much higher noise level.

The biggest problem that has developed involves a discrepancy between the bucket and ocean measurements. We would expect that all of the channels would give similar estimates for the skin temperature after each was independently calibrated using the bucket system. This has not been the case as there are several significant and persistent differences between the measurements. The differences can be traced back to the fact that the polarized measurements of the ocean and the bucket differ much more than they do for the nonpolarized measurements. The bucket calibration system assumes that the changes in the measurements between the ocean and bucket views are consistent (but not constant) between channels. These results indicate that there may be some fundamental difference between what the radiometer is seeing in the bucket and in the ocean. For the most accurate

calibration, this difference must be resolved. This same problem may exist in earlier single channel measurements, but there would be no way of detecting it.

All of the skin measurements have been averaged into one-minute values to be consistent with measurements of the bulk SST and meteorological quantities taken by the ship as well as measurements of downwelling solar and longwave radiation that we took using Eppley radiometers. A file containing all of this information has been created and used in some preliminary analyses to be described below. The final version of this file will depend on what is determined concerning the bucket calibration issue.

One final data set will be collected this May and June in the South Atlantic from the F/S Meteor. We will again be using the Ophir MISTRC to measure skin temperature so we should have more data to address the issues described above. Other measurements will include downwelling solar and longwave radiation from Eppley radiometers and bulk temperature measurements at a depth of 10 cm taken from a float when the ship is on station. All of the instrumentation was prepared last month and is currently being shipped to meet the ship. Combined with the other data sets described above, we will have a fairly comprehensive data set for the analysis of skin SST and the bulk-skin temperature difference.

Analysis of Skin SST

Using data from the 1984 Meteor cruise and preliminary data from the Vickers, we have performed some studies of the bulk-skin temperature difference and its relationship to heat flux. Two of the primary goals of this research have been to improve our physical understanding of what governs the bulk-skin temperature difference and to develop a more physical approach for predicting its value. We have attempted to use a primitive equation based mixed layer model to predict the near-surface temperature profile thinking that this would be an improvement over many of the simple parameterizations that have been presented.

This year, several modifications were added to the mixed layer model to improve its performance relative to coarser resolution bulk measurements. We have incorporated these changes into our skin model and have been able to run the model successfully (with reasonable turbulence characteristics) at the resolution necessary to study the skin. Some work is still needed to improve the model's performance at low wind speeds and much more verification is needed, but the model continues to show promise as a useful tool.

To resolve the skin and ensure proper turbulence behavior, we have had to run the model with a vertical resolution of 0.5 mm and a temporal resolution of 0.1 s. At this resolution, however, the model requires too much computational time to be applied on a large scale. To apply the model in a practical sense requires a different approach. We have coupled a parameterization of the skin layer to the top of a lower-resolution mixed layer model. While this solution may not be as physically attractive, it offers a compromise between the full model and a single parameterization.

One of the biggest limitations of the parameterizations (aside from the limited physics) is their application to ΔT measurements taken relative to varying depths. While the parameterization might accurately reflect the temperature drop across the skin layer, there can also be a significant temperature change between the base of the skin layer and the depth of the bulk measurement, especially during the daytime. The approach we have developed is to use the parameterization to predict only the temperature drop across the skin and then the model to predict the profile from the base of the skin layer to a depth of 50 m. This eliminates the need for the high resolution model and simplifies what must be modeled with the parameterization.

The choice of the skin-layer parameterization becomes critical in this approach. We investigated several different approaches presented in the literature and developed a slightly modified version of our own. Our approach is based on the idea of surface renewal. We assume that the heat transfer through the skin layer occurs by molecular conduction and then relate the thickness of the skin to the time scale of the surface renewal. By taking this time scale as the Kolmogorov microscale, we were able to obtain improved correlation between predicted and measured nighttime ΔTs over the published parameterizations of Saunders (1967), Liu et al. (1979) and Schluessel et al. (1990). Our comparisons were limited to nighttime to prevent diurnal warming from affecting the parameterization.

We coupled this parameterization to the lower-resolution mixed layer model and tested the combination on periods from both the Vickers and 1984 Meteor cruises. The results from application to the Vickers data are shown in Figure 2. The solid line indicates the observed value of ΔT relative to a depth of 4 m, the dashed line is the value computed using only the parameterization, and the dotted line is the solution from the coupled model and parameterization. The time was recorded in GMT so the left side of the plot represents the nighttime while the right side corresponds to daytime. During the night when there is little temperature change immediately below the skin layer, the parameterization does a very good job of predicting ΔT. During the day when there is warming of the upper layer, the parameterization alone cannot predict ΔT, but by adding the mixed layer model we are still

able to predict the approximate magnitude of ΔT. These results were presented at the 1994 Ocean Sciences Meeting in San Diego.

In the coming year we plan to proceed further with this work. We will work more with the full skin-resolving model to see if it can help us select the skin parameterization. We will also work with the parameterizations to find the most physically sound method for determining ΔT. All of the analyses performed on the Vickers data will be repeated with the Baldrige data. Any resulting modifications will be tested under a wide range of conditions to ensure that our approach is robust and reliable. The parameterizations all demonstrate the connection between ΔT and the air-sea heat flux and wind speed. We will begin to apply our work to remote determination of the net heat flux.

Mapping SST for TOGA COARE

A second part of this project involved the mapping of satellite SST for TOGA COARE. From October 1992 through March 1993 we collected AVHRR data from sites in Townsville, Australia and Kwajelein and produced SST maps from the NOAA-11 data as soon as possible. These maps were all made available via anonymous ftp here at the University of Colorado. In the past year we have finished processing all of the remaining NOAA-12 data that we collected.

These initial SST maps were produced using the NOAA operational MCSST and CPSST algorithms. We compared the SST values with available drifting buoy data from the region and found consistent offsets on the order of a degree. To make improved SST maps for the TOGA COARE researchers, we are producing a satellite skin SST algorithm specifically for this region. We have performed atmospheric simulations using skin temperature and radiosonde data collected during TOGA COARE and CEPEX and used the results to generate algorithms for both NOAA-11 and NOAA-12. Comparisons between the satellite products and in situ skin temperature measurements showed that the simulations for NOAA-12 were more reliable. As a result, the NOAA-11 algorithms were modified to produce values consistent with the NOAA-12 measurements. Direct generation of algorithms from the in situ data is not possible because of the small number of skin temperature measurements. We hope to finalize our algorithms after receiving some of the other aircraft and ship-based radiometric measurements taken during TOGA COARE. When the algorithms are finalized, we will redo all of the SST maps and make them available to any interested researcher. We have delayed any analysis of the satellite SST data until the new maps can be created.

We are also collecting historical data between 1990 and 1992 from the site in Townsville. We have begun processing this data and plan to make SST maps for the entire 3-year period. The goal is to create a 3-year climatology of the region with which we can compare the measurements from TOGA COARE. This work will continue in the following year as we finalize our algorithms and receive the remainder of the data.

References

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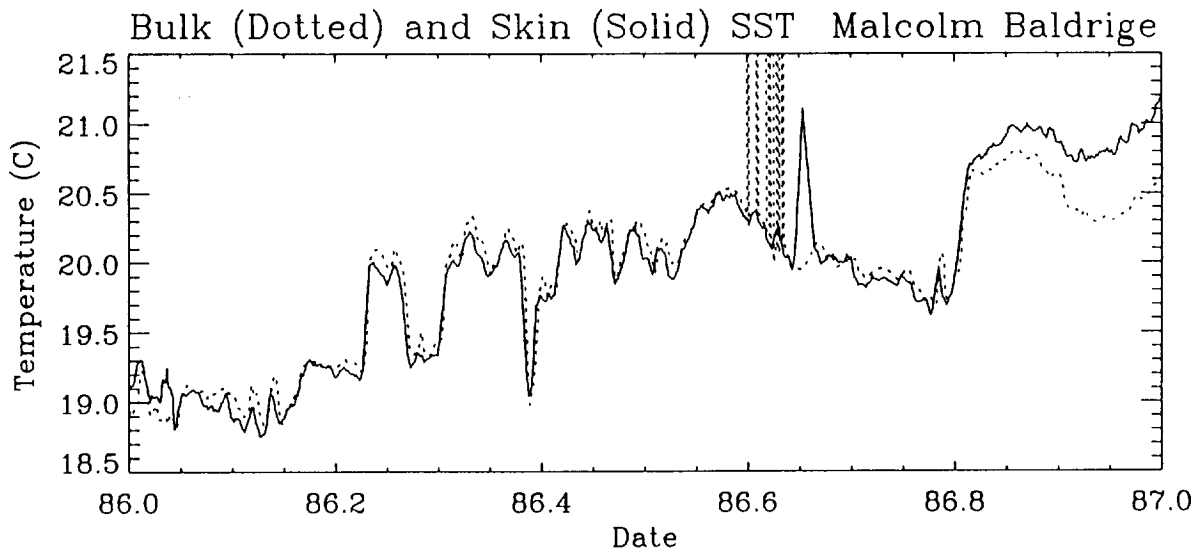
Figures

Figure 1: One day time series of bulk and skin SST measurements taken aboard the R/V Malcolm Baldrige in 1990. Bulk temperatures are shown with the dotted line, skin temperatures with the solid line.
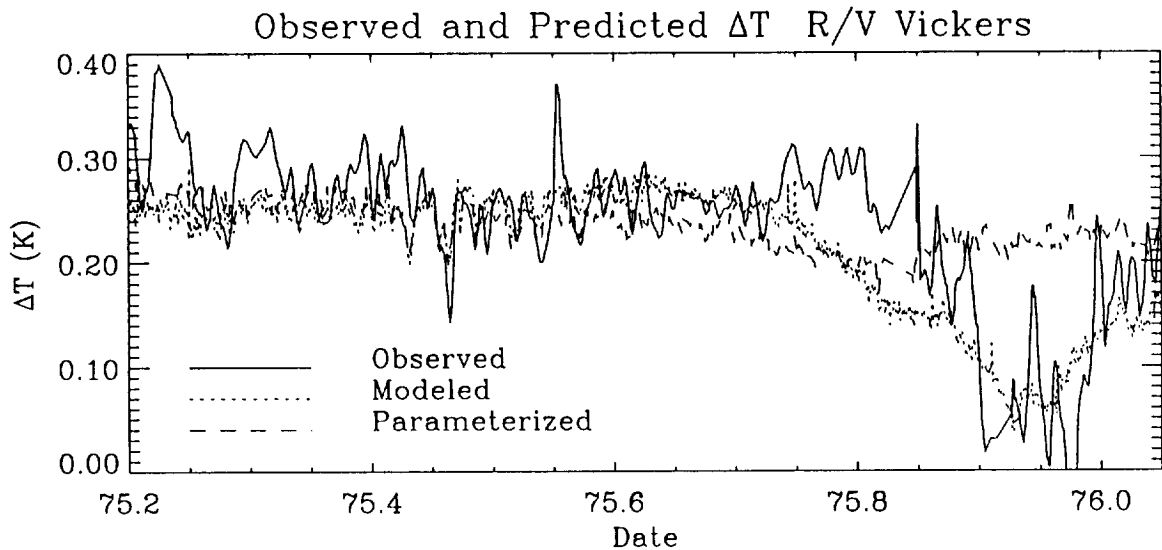

Figure 2: Comparison of observed and predicted values for the bulk-skin temperature difference. Observations from the R/V Vickers in 1993 are shown with the solid line. The value predicted with only a skin layer parameterization is shown with the dashed line. The dotted line shows the value predicted when the parameterization was coupled with a mixed layer model.